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INSPECTION, SAMPLING AND TESTING [1/]

by

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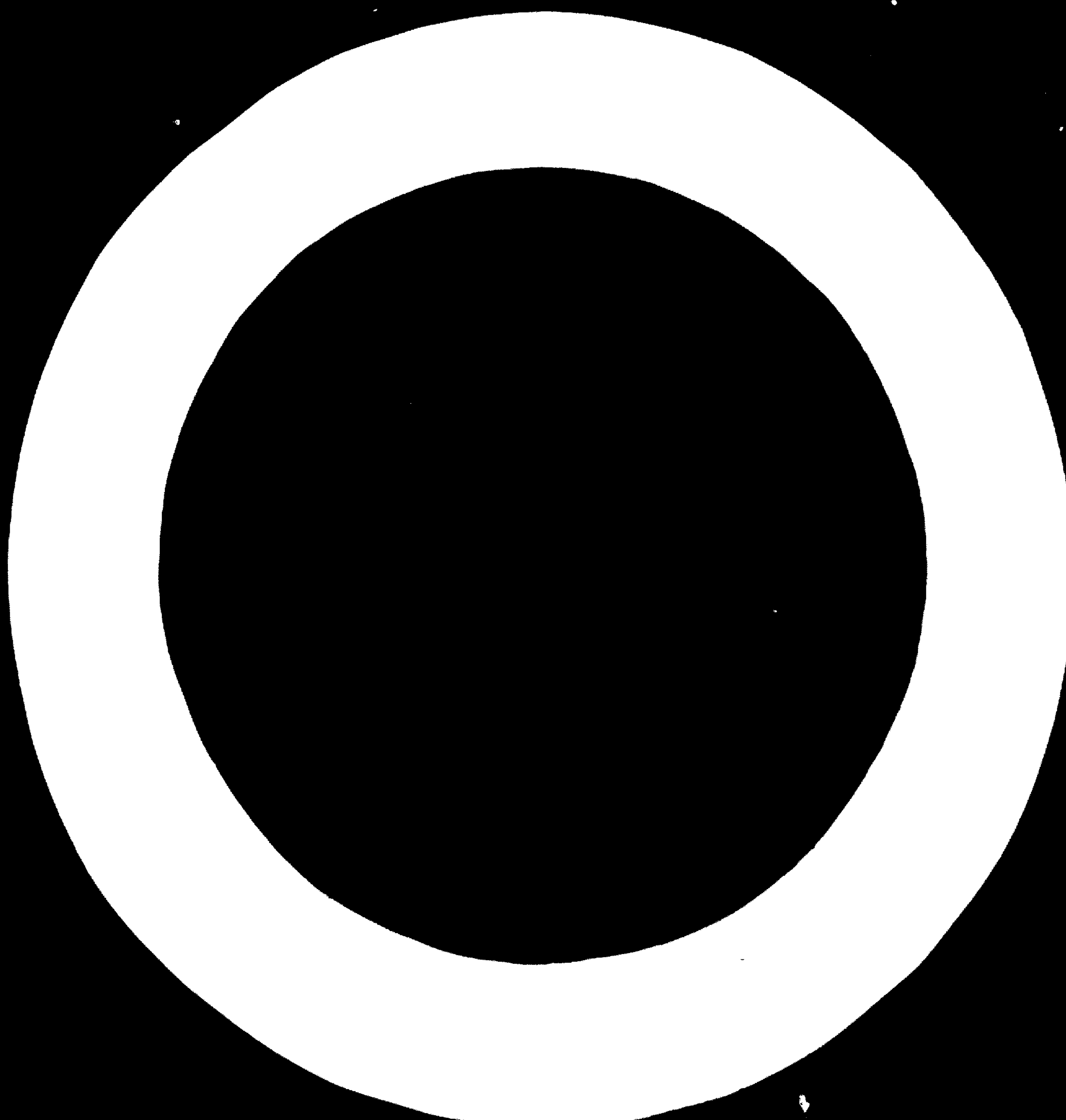


1. Quality Control and Inspection.

It is difficult to separate quality control, as an isolated system, from the production process of modern industry. Quality control consists of many activities undertaken simultaneously with general outlines elaboration of new launchings. These activities are continued in accordance with the progress of constructional and technological studies, in accordance with investment in means of production and manpower of the industry, before production launching / so-called pre-productive sphere/, whereafter carried on continously in two spheres, namely:

- in the sphere of technological process
- in the sphere of operation /service/ of products

as long as the production is being realized in accordance with the fixed specification.

The activities connected with quality control can be divided into two categories, namely:

- the first category which ensures the quality of design, i.e. a proper construction level, recipe, production pattern. The level of requirements results from these factors.

- the second category, which ensures the quality of conformance, i.e. respective conformance of consecutive batches, lots or single products to requirements fixed in the specification.

An example has been mentioned, which illustrates the activities, connected with quality control in the sphere of general outlines of new launchings. Fig. No 1 shows a series of activities indispensable for production launching, properly chosen in the respect of quality design.

This process is more or less complex, according to the importance of the being launched production, its scale, the extent to which it is connected with other industries. However there are no industries nowadays, with which it would not be more or less applied. Fig. No 2 illustrates the diagram of quality of design control, i.e. a series of activities, and their straight and feedback connections composing the preperation of new production. There is nowadays the opinion that correctness of quality control process has an essential influence on the economic success of the industry in the conditions of stiff competition on the international market.

Launching a new production in a serialized scale requires the undertaking of a number of activities composing the quality of conformance control, and giving the reason for the improvement of specification and requirements of the next improved product / so -called long feedback loop of the quality control spiral/, or improvement of the current production / short feedback loop of the quality control spiral/. The diagram of quality of conformance control is shown in Fig. No 3. Among the activities represented by the diagram, the following can be distinguished:

- connected with decision making of acceptance or rejection of a product or an operation, defined as quality inspection,
- connected with decision making of changing the specification or production process, defined as quality prevention.

2. Inspection Goods and its Relationship with Production

The activities connected with taking the decision concerning acceptance of carried out operations, or their return to correction or destruction, take, according to the type of produced goods, 10 -30% of the total labor consumption of the production. These activities are carried out by operators /operator control/, or by workers of a separate quality control service in the enterprise. In order to establish the inspection procedure in the technological process, it is necessary to elaborate a "process flow chart". It consists in a schematic setting of operations, such as production, inspection, manipulation, carried out one after the other. These operations result in processing the materials, delivered to the plant, into final products.
In order to separate inspection activities, they are marked symbollically by a square, whereas production operations are marked by a circle. Fig. No 4 illustrates the process flow diagram for an electronic

valve. The project of inspection in a technological process resolves itself into:

- choice of control stations,
- choice of control methods and tools,
- assignment of a person responsible for decision making concerning acceptance or rejection of a product or batch,
- establishing the criteria of acceptance or rejection,
- elaborating the principles of quality reporting.

The above mentioned problems are interconnected, allowing the inspection organizer for a great deal of freedom in the choice of the most suitable variant according to:

- serial production process,
- degree of requirements severity for the products /the value of losses resulting from non-detection of a single defective product in comparison with the cost of its detection/.
- qualifications of personnel and the efficiency of motivation system,
- condition and precision of machines and appliances and stability of the production process,
- possibilities of equipping the production process with apparatus and measuring instruments.

The particular factors determining the inspection organization are varied, and on account of this fact, it is difficult to elaborate an uniform pattern for various industries and enterprises.

There are however some regularities which will be shortly discussed below.

3. Choice of Control Stations in the Production Process.

In principle, the inspection activities should be connected with each operation of the technological process. In a properly organized production process, the overwhelming majority of these activities should be carried out on the principle of operator control. There are however, some operations or groups of operations, for which inspection activities should be carried out by special inspection personnel. Usually special control stations are also set up for:

- incoming inspection,
- final operations in particular departments of the enterprise,
- final operations of plant production,

and very often, additionally:

- special, important operations, even when they are in the middle of the production line.

Apart from the control stations, fixed in the production process, a system of patrol inspection can be introduced. The aim of this system is not exactly the quality control of products but rather the supervision of technological process and operator control correctness.

4. Inspection Methods

4.1. 100%-inspection.

Inspection activities, connected with the acceptance or rejection of products differ in accordance with the fact whether the inspection includes product quality or batch quality. When the purpose of the inspection is to determine the conformance of the product with fixed requirements, the applied method is 100%-inspection.

This method was commonly applied in the industry before the 2-nd World War. As the cost of this inspection method is very high, it has usually been deformed into the form of pseudo 100%-inspection, i.e. into an accidental, unplanned, random inspection of a part of the current production.

Nowadays, in properly organized quality control systems 100%-inspection is applied:

- for the control of critical characteristics of products /i.e. the characteristics, which when not fullfilled may result in a danger for human life or may lead to damages exceeding considerably the value of the controlled product/,
- for segregation of rejected batches on the basis of a fixed sampling procedure,
- for solutions of active inspection, i.e. inspection carried out by automatic measuring instruments, generally coupled with production appliances.

The 100%-inspection does not warrant the detection of every defective product. During this inspection method, as after all, during each other, it is necessary to take into account the possibility of committing an error:

- of the first kind, when a product, which meets the requirements, is rejected;
- of the 2-nd kind, when a product, which does not meet the requirements is accepted.

Interesting examples of 100%-inspection effectivness appraisal are presented in the bibliography.
Here is an example taken from J.Obalski's textbook "Statistical quality control during the production process" /publ. PWT - Warszawa 1955/:

"A big batch of products, in which exactly 100 defectives were present, was subjected to three successive inspections carried out by highly qualified inspectors. The following result was obtained:

the 1-st inspection detected 68 defectives
the 2-nd inspection detected 18 defectives
the 3-rd inspection detected 8 defectives

After three 100%-inspections, 6 more defectives remained in the batch. A specially selected team of inspectors carried out the fourth inspection and detected 4 more defectives. Two more defective products remained in the batch."

The causes of a low efficiency of 100%-inspection are due, first of all, to the process of tiredness, accompanying monotonous functions of 100%-inspection.

This monotony leads to deconcentration of attention and to deformation of inspection correctness, errors of 1-st and 2-nd kind and unreliable information.

Essential difficulties in the application of 100%-inspection occur in the following cases:

- large batches of products /practically above 500 pieces/, owing to a high labor consumption and effects of tiredness,
- granular or continuous products, owing to the fact, that carrying out 100%-inspection of the whole batch is technically unfeasible,
- single products, when the number of parameters subjected to the inspection is very large,
- any batch, when destructive testing is applied.

The necessity of finding the adequate inspection methods for these cases resulted in the development of statistical methods.
When the statistical method of inspection is concerned the notion of quality does not refer to a single product, a batch or lot of products. The quality of a batch is defined by its defectivness, i.e. by proportional participation of defective products in a batch or by the number of defectives per 100 pieces of the product.

Statistical methods have been directed nowadays towards a few groups of problems, namely:
- acceptance methods,

- methods of current inspection during the production process /testing of process capability and stability/,
- reliability testing,
- experimenting methods.

The most important of them will be discussed below.

4.2. Acceptance methods.

When the risk of commiting an error /especially the error of 2-nd kind/ is not attended by heavy losses, we are allowed to tolerate an accepted quality level /AQL/ in the batch, on condition, that an acceptance plan exists, which will ensure:

- low probability of accepting a batch, which has the defectivness higher than the agreed AQL,
- high probability of accepting a batch, which has the defectivness lower or equal to the agreed AQL.

When the contractor and the customer agree, that from the delivered N-sized batch, a n-sized sample will be taken, and that the batch will be accepted if the number m of bad pieces, detected in the sample, will be smaller or equal to the number Ac, then, on the basis of probability mathematics, it is possible to determine the acceptance probability of the batch, according to its defectivness.

Naturally, when the batch does not contain any defective pieces, then it will be certainly accepted, whereas in accordance with the increase of defectivness, the acceptance probability decreases. Fig. No 5 represents the dependence of acceptance probability of a batch upon its defectivness. This dependence is called Operating Caracteristic Curve - OC, which can be calculated for every acceptance plan. /Fig. No 5 has been taken from MIL 105 D, a basic acceptance procedure by attributes/. The operating characteristic has two specific points, namely: AQL of a high acceptance probability /within the range of 87-92%/ and LTPD /lot tolerance percent defectives/ of a low /range 10%/ acceptance probability. These two points determine the OC Curve Slope, which illustrates the strictness of acceptance.

The OC curve gives much information about the usefulness of acceptance plan for the customer and for the contractor, determining the risk of rejecting a batch of a low AQL for the first of them, and the risk of accepting a batch of high defectivness LTPD for the second one. When this plan is applied only occasionally, these risks have only a theoretical meaning. It is known, that during a single acceptance, there is little risk of accepting a batch of a higher defectivness than LTPD, but it is not known whether this case will not concern the batch being just accepted.

This is a different matter however, when the plan is applied continuously for a consecutive acceptance of delivered products. Owing to statistical regularities the customer may really expect low defectivness in the majority of batches. Moreover, if all rejected batches are segregated and all included defective products removed, then, after having mixed accepted batches and rejected batches devoid of defectives, detected during the 100%-inspection, the customer will get an average outgoing quality /AOQ/ lower than the defectivness before the inspection. AOQ, conditioned by the defectivness before the inspection, has a characteristic point, called average outgoing quality limit /AOQL/, determining what is the highest defectivness, which may be expected by the customer in many accepted batches. The acceptance of AOQL is, for the customer, an essential criterion of his agreement for the acceptance plan. On the other hand, the contractor is interested in the reduction of the number of functions connected with the inspection of sample and 100%-segregation of rejected batches. Every plan is characterized by so-called Average Total Inspection curve /ATI/ of a shape dependent on batch defectivness before the inspection. The contractor should choose such a plan, for which, ATI is the lowest, for average defectivness of delivered batches before the inspection.

In order to make the choice of plans easier, they have been formulated in typical procedures from among which Dodge-Romig tables and Military Standard 105 D, are the most often used. Particularly, the latest one has become the elaboration basis of the majority of domestic and regional acceptance standards, and owing to this fact it is worth devoting some attention to it.

4.3. An example of acceptance sampling by attributes.

MIL-105 D is designed for the acceptance of batches of products, for which the quality can be determined by means of the qualification: good or defective.

Defects, according to MIL-105 D, are divided into three groups, namely:

a/ critical defects, i.e.: "the defects which according to experience or estimation may cause a danger for the user or may result in a hold-up of final products of great importance as ships, aeroplanes etc."

b/ important defects, i.e.: "the defects, which are not critical but which may cause a damage or limitation of product's usability in the "sphere, for which it has been designed".

c/ minor defects, i.e.: "the defects, which do not necessarily cause a limitation of product's usability in the sphere, for which it has been designed, but are revealed in the form of inconformity with established standards, having no essential influence on product's effective operation."

Defective products are classified according to the character of defects. According to the procedure, there are distinguished:

a/ critically defective products, i.e.:"the products, which possess one or severel critical defects, and perhaps also important and minor defects."

b/ seriously defective products, i.e.: "the products, which possess one or severel important defects and perhaps also minor defects, but which do not possess critical defects."

c/ secondarily defective products, i.e.: "the products which possess one or several minor defects, but which do not possess critical and importent defects."

Coordinates of operating charecteristic curve.

Defectivness is defined as:

a/ proportionel participetion of defective products among inspected products:

$$W = \frac{\text{number of defective products}}{\text{number of inspected products}} \cdot 100\%$$

b/ number of defects per 100 products:

$$W = \frac{\text{number of defects}}{\text{number of inspected products}} \cdot 100\%$$

The introduction of number of defects per 100 products enables to apply an uniform procedure not only for batches but also for complex single products, in which several various features are inspected. The scale of defectivness is included between the limits 0 and 2000%.

Operating characteristic curves are subordinated to particular plans. These operating characteristic curves determine the acceptance probability of a batch according to its defectivness. A point called AQL /acceptable quality level/ determining the acceptable defectivness can be distinguished on the operating characteristic curve.

The acceptance probability of a batch, which has AQL defectivness, is high, but it ranges from o,86 to o,99 in particular plans /the higher is the probability the higher is AQL/. AQL is defined as: "maximum defectivness, which for the customer's purposes, can be considered sufficient, as the mean of production process."

The customer, fixing a determined value of AQL for particular defects or groups of defects, tells the contractor that the majority of batches of products, submitted to acceptance, will be accepted if the defectivness of these batches will not exceed AQL." The determination of AQL does not mean that the contractor has the right to deliver any defective product willfully.

Various AQL-s can be determined for particular groups of defects. For the values below 10%, AQL can be expressed either as a part of defective products in the batch, or as the number of defects per 100 pieces.

For the values higher than 10%, AQL is expressed as the number of defects per 100 pieces. Standard values for AQL are given in the table of MIL-105 D plans.

The MIL-105 D procedure "reserves" for the customer the right to reject every bad unit detected during inspection, regardless of the fact, whether the whole batch will be accepted or rejected.

At the same time, customer's right is reserved

" to carry out the inspection of every unit by the contractor, in the respect of critical features and to reject the whole batch after having detected even a single defect during the inspection" The batches rejected, in the result of the inspection, according to a fixed plan, remain for the return to the contractor. A repeated acceptance of the rejected batch can be made only after carrying out the inspection of every unit /by the contractor or at his expense/, and after removing or mending all defectives. The MIL-105 D procedure provides for three kinds of inspection: normal, tightened and reduced. Inspection always begins with the normal one. The principles of passing on to another type of inspection are the following:

a/ from normal to tightened one:

when two of five consecutive batches, being accepted according to normal inspection, are rejected;

b/ from tightened to normal one:

when five consecutive batches are accepted according to tightened inspection;

c/ from normal to reduced one:

- when 10 consecutive batches /or more according to the table/ are accepted according to normal inspection, or
- when the whole quantity of defective pieces detected in 10 previous batches, according to normal inspection, is not bigger than the corresponding number shown in the table No 8 /For double sampling plans or multiple samplings it will be the number of defective pieces in all samples of consecutive degrees of inspection, or
- production process is under control

d/ from reduced to normal one:

- when the batch is rejected according to reduced inspection,
- when the conditions of a controlled production process have been spoiled.

When, according to the tightened inspection, 10 consecutive batches are rejected / the acceptance of the batch should be suspended until the quality of products is improved.

The acceptance plan, contained in MIL-105 D, makes known:

- the number of pieces in the sample /or in a set of samples in double sampling plans and multiple samplings/, and
- tolerated number of defective pieces in a sample /samples/, according to chosen:
  - tolerated defectivness AQL, and
  - code letter of the sample size.

The code letter is connected with sample size, which is chosen according to sample size /within the range 2 - 500,000 pieces/ and according to inspection level. Inspection levels, determining the ratio of sample size to batch size have been standarized in the form of three normal levels marked I, II and III, and four special levels S_1, S_2, S_3, S_4 /If there are no special circumstances the II level should be applied/.

The procedure provides for three types of plans

- single sampling plan
- double sampling plan
- multiple sampling plan.

Fig. No 6 presents an inspection scheme, carried out by means of a single sampling plan, fig. No 7 by means of a double sampling plan and Fig. No 8 by means of a multiple sampling plan.

In the procedure for every plan, the operating characteristic curve /OC/, the value AQL and the value LTPD, can be found.

4.4. Acceptance Sampling by Variables

We can apply a different type of acceptance procedure for many groups of products, than it has previously been described. In this procedure the decision of acceptance or rejection of a batch is taken on the basis of mean value estimation and controlled variances of product attributes in the batch.

The inspection is carried out for a definite product attribute, which can be expressed in variables.

The product is considered to be good when the variable X of this attribute does not exceed the value X_o, fixed in the contract.

Similarly as in previously discussed acceptance sampling by attributes, a n-sized sample is taken from a N-sized batch. On the basis of X_1 controlled variable measurement, in each sample element, the mean value is calculated:

$$\bar{x} = \frac{\sum_i x_i}{n}$$

and so called standard deviation:

$$\sigma = \sqrt{\frac{\sum_i (x_i - \bar{x})^2}{n}}$$

Acceptance criterion is established according to a desirable characteristic CO, as a condition, when:

$\bar{x} \geqslant x_o + k\sigma$ the batch is accepted

$\bar{x} < x_o + k\sigma$ the batch is rejected

The choice of plan condition depends on the fact, whether the value σ is known, or it is estimated

on the basis of a sample. The values for k, according to criteria required by the contractor and customer, are included in standard procedures.
The most commonly known procedure is MIL 414 ACCEPTANCE SAMPLING BY VARIABLES, it is however being at present amended, owing to many objections, encountered during its practical application.
Sample size in acceptance sampling by variables is much smaller than required for ensuring a similar OC in acceptance sampling by attributes. It should however be remembered that time consumption is bigger for the measurements of variables and in consequence of this fact, it is necessary to check by which procedure total acceptance functions are shorter.

4.5. Shewart Control Charts

The idea of statistical inspections, as it has already been previously emphasized, resolves itself into following not only the quality of a single product but also the quality of a set or a batch of products. In the overwhelming majority of cases, there is no need to inspect every product during the technological process, it is sufficient to inspect the following parameters:

a/ whether the process is consistent /i.e. whether the dispersion centre of the controlled attribute, observed in many products, is near the midtolerance/,

b/ whether the process is precise /i.e. whether the sixfold standard deviation of the dispersion is smaller than the tolerance area/,

c/ whether the process is controlled /i.e. whether it maintains its consistency and precision/.

The analysis of process consistency and precision is being carried out within the limits of so-called process capability studies. Testing techniques are usually based on the analysis of distribution histogram and aim at the detefmination of momentary process defectivness. The analysis of stability /which contains also testing of consistency and precision but during a longer period of time/ is carried out on the basis of Shewart control charts.

Shewart control charts /Fig. No 9/ is a curve formed by points of mean values and ranges determined in samples /of size about 4-5 pieces/ taken successively from the current production. It is clear, that when samples are taken from one set and their mean values are calculated, then due to accidental phenomena, these mean values will differ among themselves in various samples. The essence of stability inspection is inherent in the determination when the observed differences among mean values from particular samples result from random choice of sample elements, and when they result from process consistency and/or process precision changes in the course of time.

One of Shewart charts, so-called $\bar{X}$,R chart, it is elaboration and application methods will be described below.

The elaboration procedure of the chart is the following:

1/ samples, containing several successively produced pieces /for instance n=4/ are taken from the current production in equal time intervals /for instance every 1/2 hour/,

2/ the mean value $\bar{X}_i$ is calculated in each sample:

$$\bar{X}_i = \frac{X_1 + X_2 + X_3 + X_4}{4}$$

and the range R_i, which is the difference between the largest and the smallest controlled value in the sample:

$$R_i = X\,max - X\,min$$

3/ after having collected data from 25 samples the grand mean is calculated:

$$\bar{\bar{x}} = \frac{\sum_1 \bar{x}_i}{25}$$

and the mean range:

$$\bar{R} = \frac{\sum_1 R_i}{25}$$

4/ coefficients A and D, dependent on sample size n, are taken from tables of standards. These coefficients are used for the determination of so-called control limits /upper and lower for mean values and upper for ranges/, namely:

$$UCL_{\bar{x}} = \bar{\bar{x}} + A\bar{R}$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A\bar{R}$$

$$UCL_{\bar{R}} = \bar{R} \cdot D$$

5/ the calculated points and control limits are plotted on a sheet. These lines are called test limits. Generally it is necessary to carry out a repeated calculation of control limits, rejecting points which are beyond the test limits;

When, during the inspection, the mean value or the range, determined in the sample, fall beyond the control limits, it is a warning signal that "the process is out of control". It is the reason for for undertaking a determined preventive action, resulting from the chart.

Shewart charts are generally applied for inspection or operator control of current production. However they can also be of great service for incoming inspection, final inspection, analysis of necessary stock and for a number of other spheres of inspection activities in the enterprise.

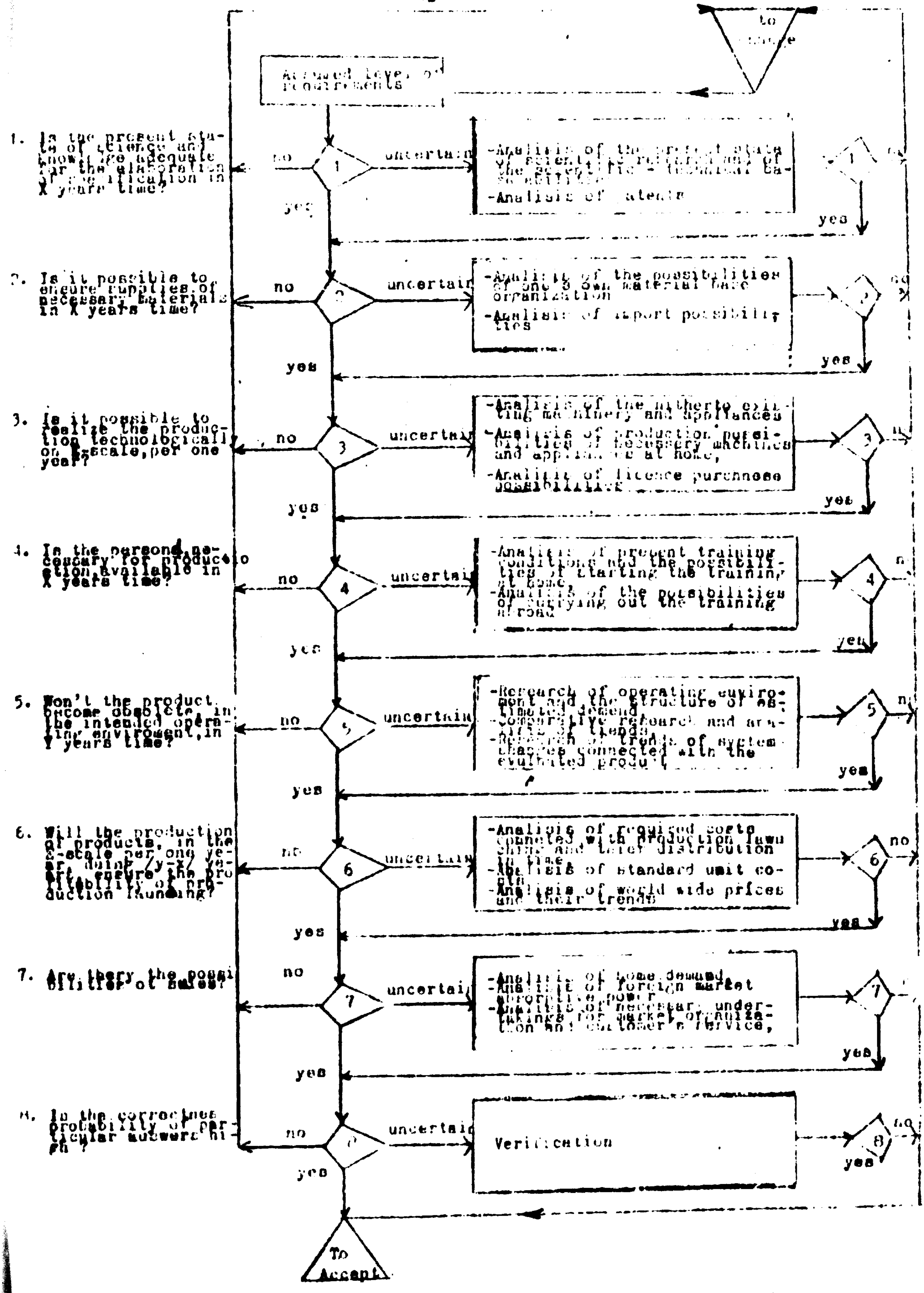


Fig 1. Quality control in the sphere of establishing assumptions for new production

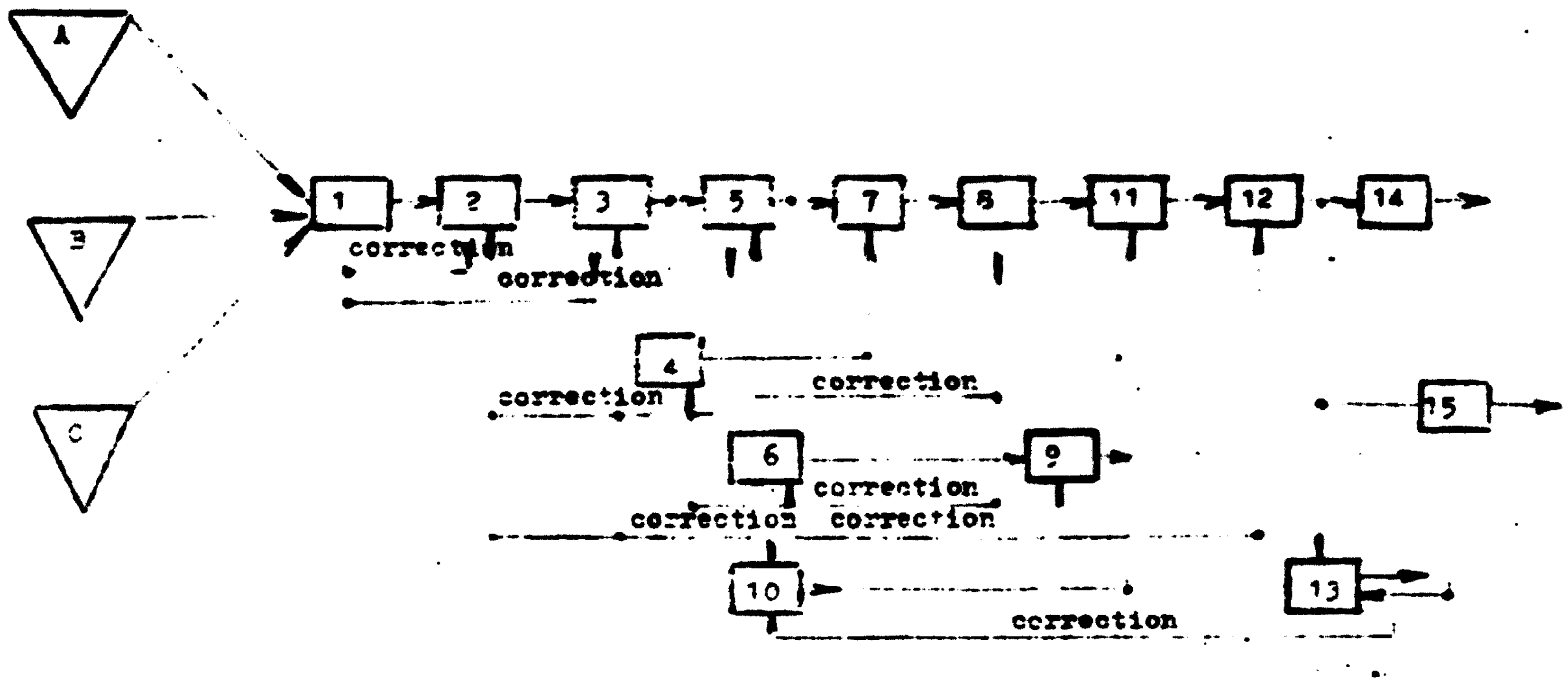


Fig. 2. The sphere of quality of design control

A- collection of data on operating euvironment and needs,
B- collection of data on the state of progress in this field
C- collection of data on the present production process

1 - establishment of assumptions /quality criteria/, 2 - ana[illegible] of feasibility /analisis of the hitherto existing information and scientific-research work/, 3 - analisis of profitability /costs analisis/, 4 - organisation of material preparation /analisis of feasibility and analisis of costs/, 5 - elaboration of construction and detailed technical requirments 6 - eleboration of technology, 7 - production of the prototype, 8 - testing the prototype 9 - investment preparation, 10 - preparation of personnel for the process, 11 - production of pilot lot, 12 - testing of pilot lot, 13 - organization of customer service, 14 - elaboration of de[illegible] 14 production [illegible] 15 - organization of environmental testing

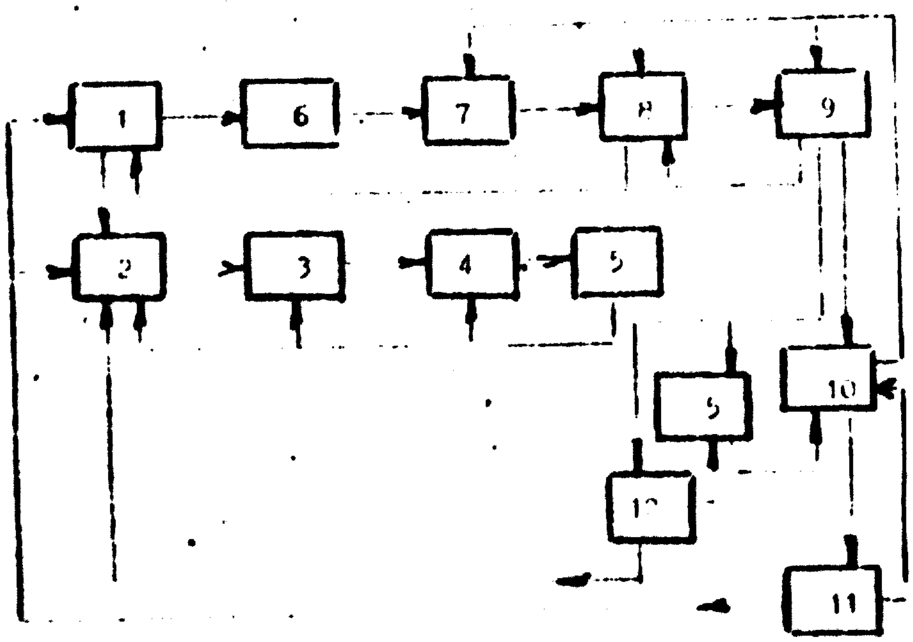


Fig. 3. The sphere of quality of conformance control

1- inspection, analisis and correction of specification, 2- methods and criteria of products evaluation, 3- detailed consignment inspection, 4- detailed inspection of all operations, 5- speed-up operating testings, 6-stabilization of the process, 7- statistical incoming inspection and classification of contractors, 8-selfcontrol of operations and analisis of defect causes, 9- verification of selfcontrol and analisis of defect causes, 10- final inspection and analisis of divergences, 11- field inspection /analisis of causes, analisis of serving complaints, 12-full operational testing in the operating environment and system verification.

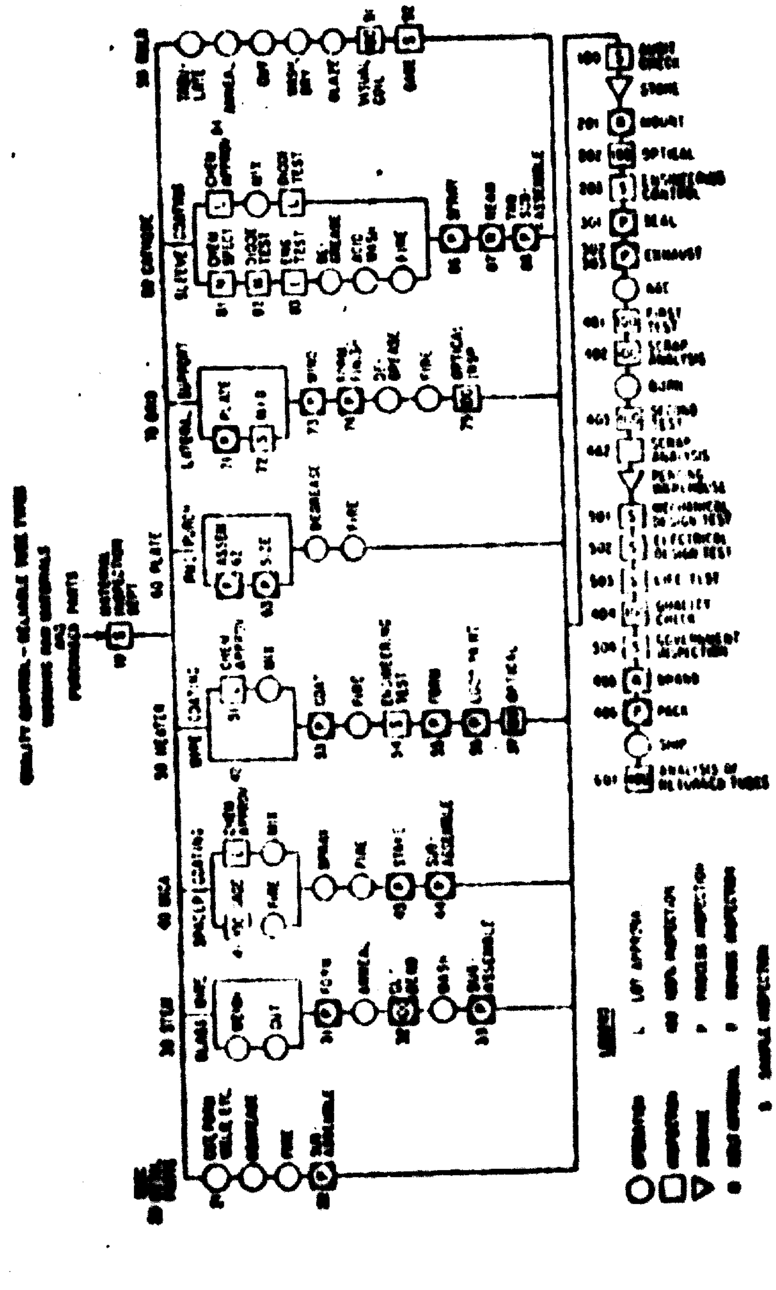
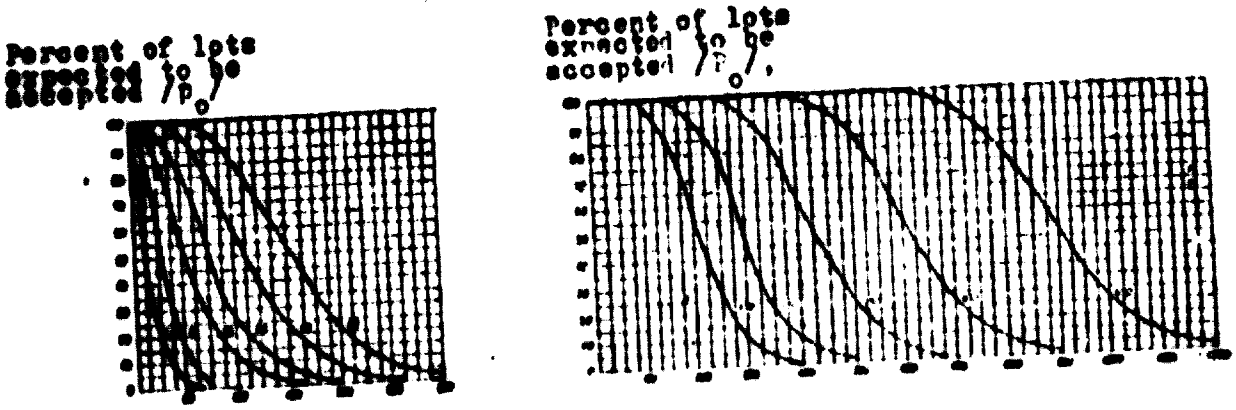


Fig. 4. Process flow chart.



QUALITY OF SUBMITTED LOTS (p. in percent defective for AQL's < 10; in defects per hundred units for AQL's > 10).

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

Fig. 5. Operating characteristic curves for single sampling plans

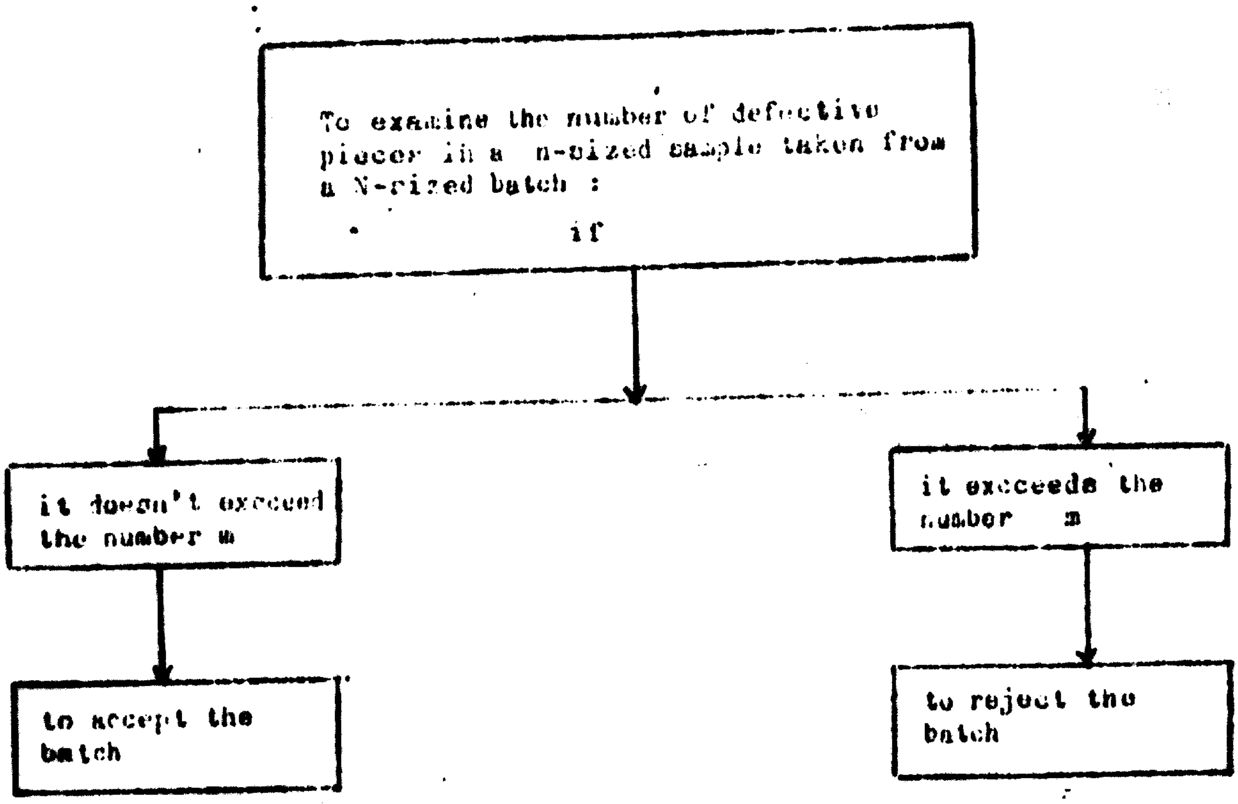


Fig. 6. Procedure scheme for the single sampling plan

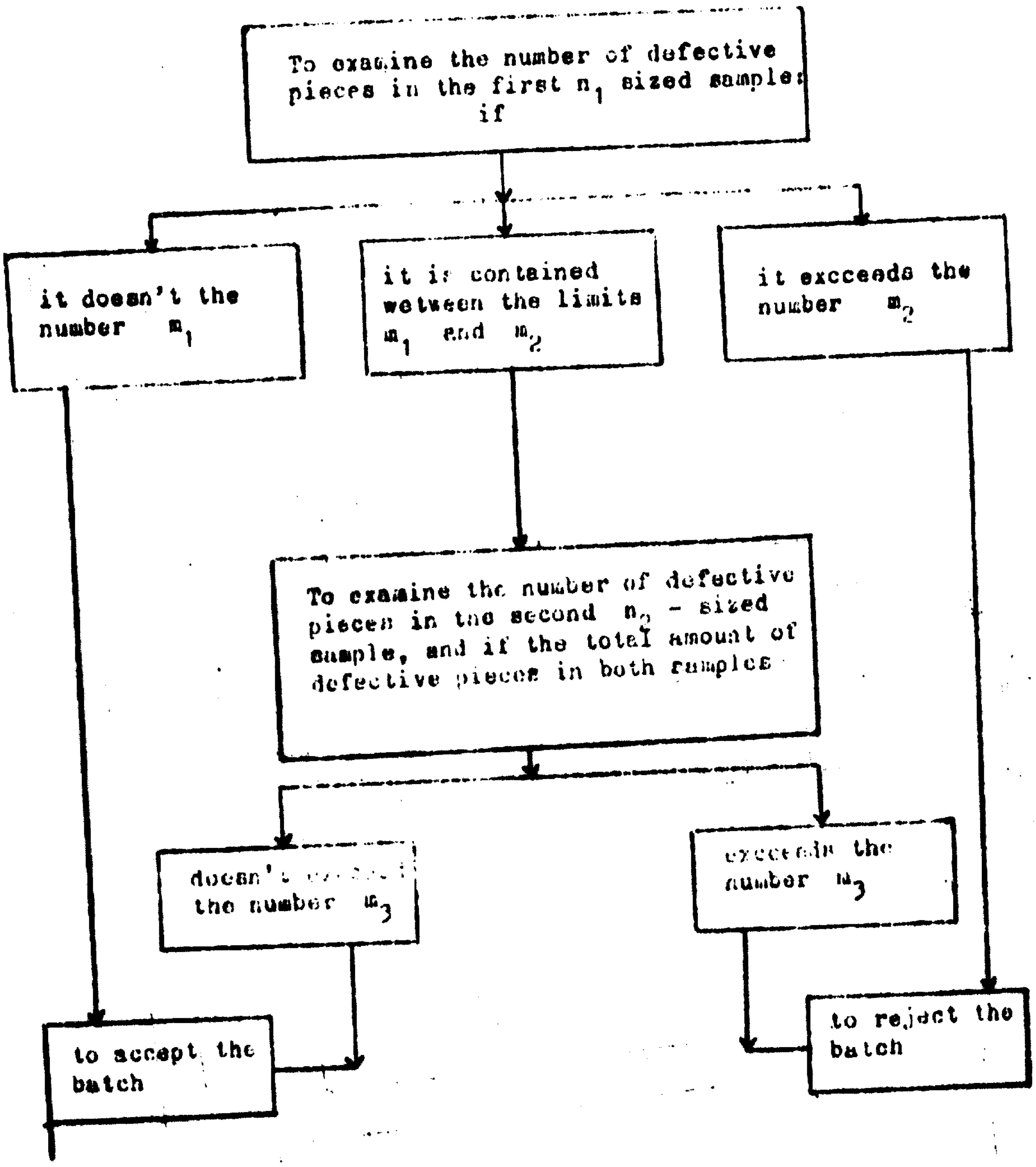


Fig. 7. Procedure scheme for the double sampling plan.

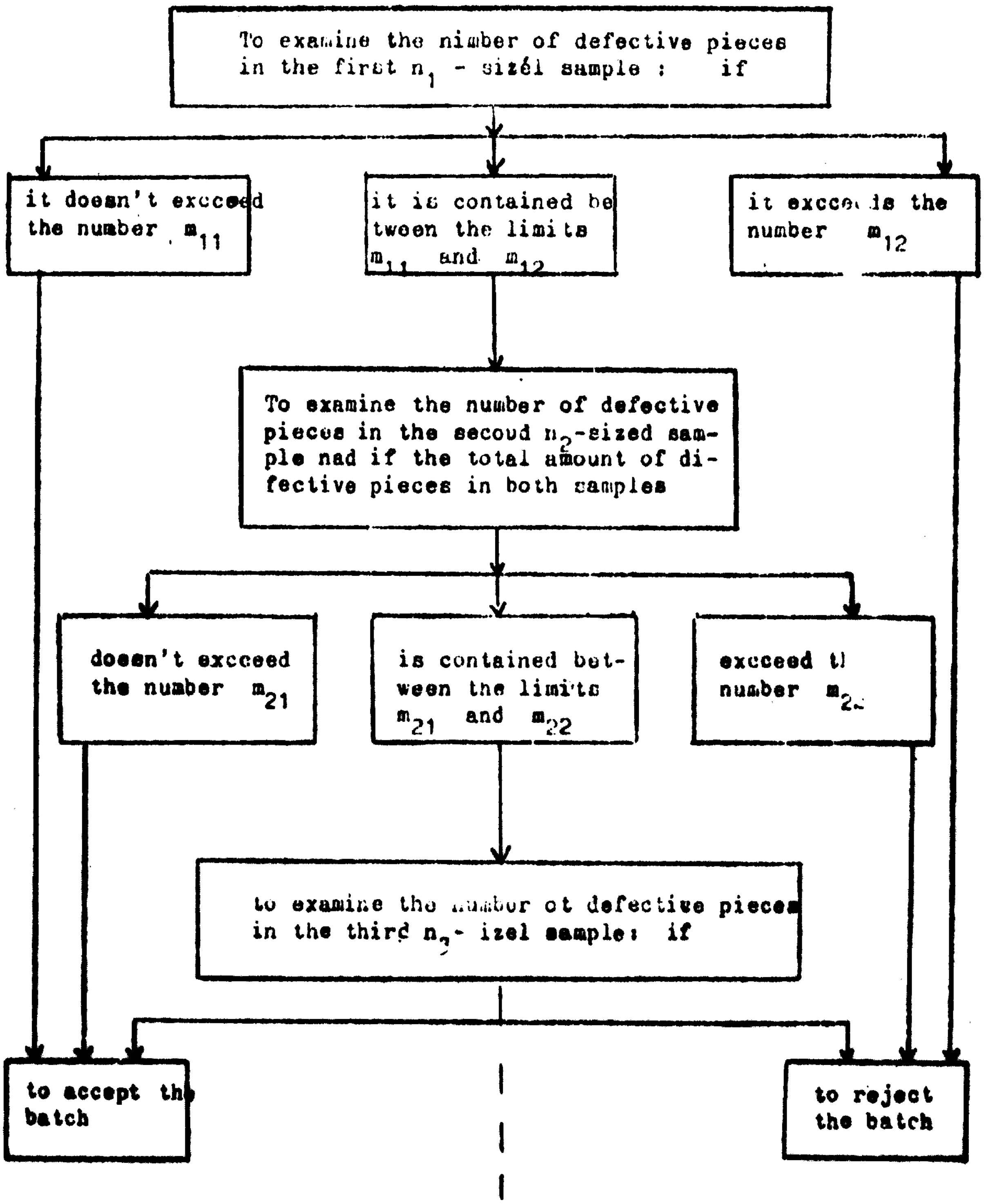


Fig. 8. Procedure scheme for the multiple sampling plan

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